

COMPARING SYMBIOTIC NEBULAE AND PLANETARY NEBULAE LUMINOSITY FUNCTIONS

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ABSTRACT

We compare the observed symbiotic nebulae (SyN) luminosity function (SyNLF) in the [O III] $\lambda 5007$ Å line to the planetary nebulae (PN) luminosity function (PNLF) and find that the intrinsic SyNLF (ISyNLF) of galactic SyNs has – within its uncertainty of 0.5–0.8mag – very similar cutoff luminosity and general shape to those of the PNLF. The [O III]/($H\alpha$ +[N II]) line ratios of SyNs and PNs are shown to be also related. Possible implications of these results for the universality of the PNLF are briefly outlined.

Subject headings: binaries: symbiotic—planetary nebulae: general—stars: AGB and post-AGB

1. INTRODUCTION

The luminosity of emission lines in a planetary nebula (PN) depends on the mass and evolutionary status of the central star (CSPN), which determine the temperature and luminosity of the CSPN, and on the nebular properties. These in turn depend on the initial mass of the progenitor, on its metallicity, and most likely on interactions with a binary companion. Therefore, the PN luminosity function (PNLF) depends on the age of the parent population (Dopita et al. 1992; Méndez et al. 1993; Marigo et al. 2004), and, to lesser degree, on the metallicity (Ciardullo & Jacoby 1992; Marigo et al. 2004), hence it varies between different types of galaxies (e.g., Ciardullo et al. 2004). However, the [O III] $\lambda 5007$ Å (hereafter [O III]) most luminous end of the PNLF, and in particular the cutoff (maximum) [O III] luminosity, seem to be similar in all large PN populations, with very small dependance on galaxy type (Ciardullo et al. 2005). This allows a very successful use of the PNLF as a standard candle, from the galactic bulge (Pottasch 1990), through the LMC and SMC (Jacoby et al. 1990), M31 (Ciardullo et al. 1989) and to galaxies at larger distances, spirals (e.g. Feldmeier et al. 1997), and ellipticals (Jacoby et al. 1996).

Some basic properties of the PNLF are well understood (e.g., Dopita et al. 1992; Méndez et al. 1993; Marigo et al. 2004; review by Ciardullo 2006a). Recently, further progress on the underlying physics has been brought through hydrodynamical PN modeling (Schönberner et al. 2007). However, a major puzzle is the cutoff (maximum) luminosity in old stellar populations, such as in elliptical galaxies, which is the same as in young populations (Ciardullo et al. 2005; Ciardullo 2006a). This cutoff luminosity of the PNLF is $L[\text{O III}] \simeq 600L_{\odot}$, and it leads to a chain of constraints (Ciardullo et al. 2005; Ciardullo 2006a): Such $[\text{O III}]$ luminosity requires the ionizing central star to have a bolometric luminosity of $L_{*} \gtrsim 6000L_{\odot}$, which in turn requires the central star to have a mass of $M_{*} > 0.6M_{\odot}$, and the progenitor to have a main sequence mass of $M > 2M_{\odot}$. Such a progenitor mass is not expected in old stellar populations. Single star evolution alone cannot account for this finding (Marigo et al. 2004).

Three explanations to the universality of the the $[\text{O III}]$ cutoff have been proposed. (i) Ciardullo et al. (2005) proposes that the most $[\text{O III}]$ luminous PNs in old stellar populations are descendant of blue-straggler type stars; namely, two lower mass stars, $\sim 1M_{\odot}$, merged on the main sequence to form a star of mass $\sim 2M_{\odot}$. (ii) Soker (2006) proposed that most, or even all, of the $[\text{O III}]$ luminous PNs in old stellar populations are actually evolved symbiotic nebulae (SyNs). Ciardullo (2006b) raised some problems with this explanation. Our reply to these will be discussed in a forthcoming paper. In this paper we limit ourselves to presenting an interesting similarity between the PNLF and the symbiotic nebulae luminosity function (SyNLF). (iii) It is possible that low mass stars in old stellar population can form massive ($\sim 0.63M_{\odot}$) PN central stars (CSPN), as mass loss rate is lower for low metallicity stars (see discussion in Méndez et al. 2008).

2. COMPARING THE LUMINOSITY FUNCTIONS

To compare SyNs with PNs we analyze the data from Mikołajewska et al. (1997; hereafter M97), who provide emission line fluxes for a sample of 67 southern SyNs, resulting from a survey of objects classified as PNs in various catalogs. We only use objects from this dataset, because it is the only one available in the literature that combines the advantages of a sizeable sample and uniform treatment with an extensive coverage of data relevant for such a comparison. M97 give also $E(B-V)$ towards the nebulae, based on their own data as well as data gathered from the literature. $\text{H}\alpha$ fluxes are available for all the objects in the catalog, and 41 SyNs also have measurements for the $[\text{O III}]$ line and a known distance. This final sample contains one D'-type object, 10 D-type, and 30 S-type, giving a fair representation of the frequencies among galactic symbiotics (e.g., Belczyński et al. 2000, Mikołajewska 2003).

For these objects we reconstruct the intrinsic nebular fluxes in the $H\alpha$ and 5007\AA lines using the extinction curve of Seaton (1979), which was also assumed by M97. From the dereddened [O III] fluxes and distances we build the *intrinsic* luminosity function (ISyNLF) of this SyN sample in $M(\lambda 5007)$, the absolute magnitude of the [O III] line, employing the definition of the apparent magnitude in this line from Jacoby (1989):

$$m(\lambda 5007) = -2.5 \log F(\lambda 5007) - 13.74 \quad (1)$$

where the flux F is in $\text{erg cm}^{-2} \text{ s}^{-1}$. Taking into account the uncertainties in the distances and in the $E(B-V)$ towards the nebulae, we estimate the statistical errors of our computed $M(5007)$ values to be 0.5–0.8mag. In Table 1 we list the SyNs with $M(\lambda 5007) < -2\text{mag}$ (that occupy the three brightest bins in Fig 1). Not surprisingly, all of them are D-type objects (i.e., containing a Mira).

The SyN sample is quite small and yet it spans $\sim 10\text{mag}$ in $M(\lambda 5007)$, so a comparison with a reasonably deep PNLf is preferred. Figure 1 compares the ISyNLF in the [O III] line to the deep PNLf of the SMC (Jacoby & De Marco 2002), assuming 19.3mag distance modulus to SMC and galactic extinction of 0.2mag (Méndez et al. 2008; we note that the extinction value is deduced by us from their fig. 9, as they do not give it explicitly). The binning in the graphs is coarse because of the low number of objects (53 PNe and 27 SyN brighter than 3mag), and the error bars are large. Nevertheless, the two luminosity functions are consistent at all points within their binomial errors and are remarkably similar in terms of the maximum brightness cutoff and general shape, including a dip around -1 – 0mag .

The intensity ratio between the [O III] and $H\alpha + [\text{N II}]$ emission lines is an important parameter in identifying extragalactic PNe (e.g., Ciardullo et al. 2002). The [N II] lines are located $\sim 20\text{\AA}$ to the sides of $H\alpha$ and so are not separated in narrow-band photometry used to find extragalactic PNs. They would be easily resolved in the spectroscopic observations of M97, but the [N II] lines in SyNs are with few exceptions either not observed or very weak compared to $H\alpha$ (e.g., Van Winckel et al. 1993; Ivison et al. 1994), so for the SyNs the distinction between $H\alpha$ and $H\alpha + [\text{N II}]$ intensities is not essential and we use the $H\alpha$ fluxes provided by M97. Figure 2 plots the [O III]/ $H\alpha$ line ratio for the SyNs and the [O III]/($H\alpha + [\text{N II}]$) ratio for M33 PNs (Ciardullo et al. 2004) vs. the absolute [O III] magnitude, $M(\lambda 5007)$. PNs in various galaxies consistently populate the area to the right of the contour line, defined in Herrmann et al. (2008). The difference in position between PNs and SyNs is clear, as is the similarity of the shape of the occupied regions. The SyN region is basically displaced with respect to the PN region by $\sim 0.5\text{dex}$ along the line-ratio axis.

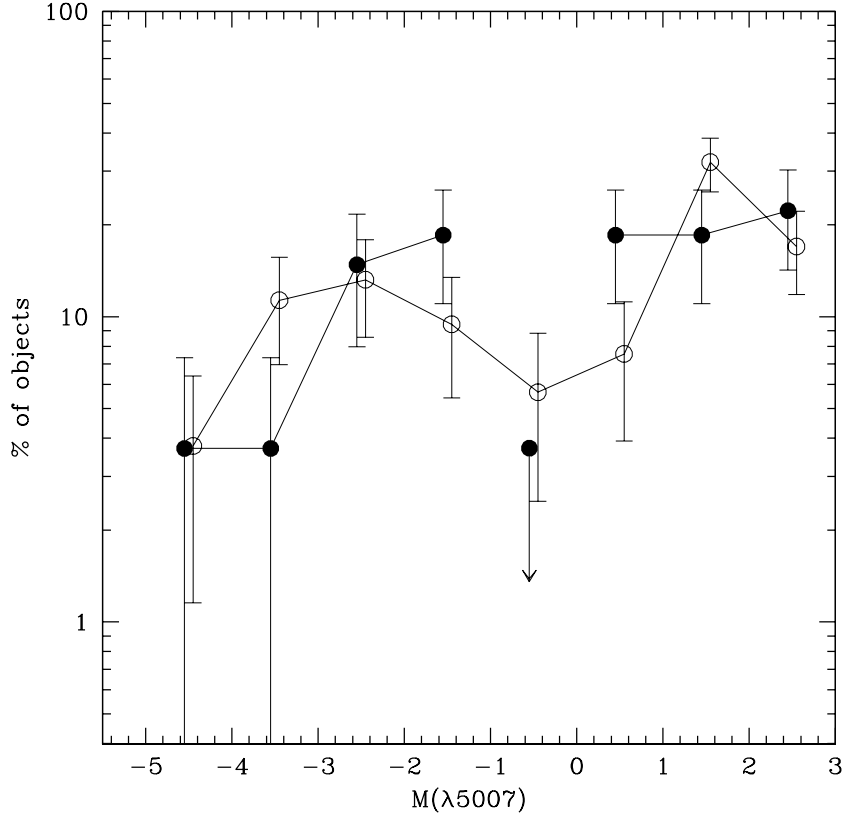


Fig. 1.— The intrinsic luminosity function of symbiotic nebulae (ISyNLF) as calculated from the sample given by M97 (filled circles) compared to the planetary nebula luminosity function (PNLF) given by (Jacoby & De Marco 2002; open circles). The points are slightly displaced from the centers of the bins to increase readability. Error bars from the binomial distribution are plotted. Both distributions are normalized to correspond to the same sample size for $M(\lambda 5007) > 3\text{mag}$. There are 53 PNs and 27 SyNs in the samples used for the plots; the leftmost point has one object in the SyN sample and 2 objects in the PN sample. The empty $[-1, 0)$ bin for the symbiotic sample is denoted by an upper limit set at $1/(\text{sample size})$.

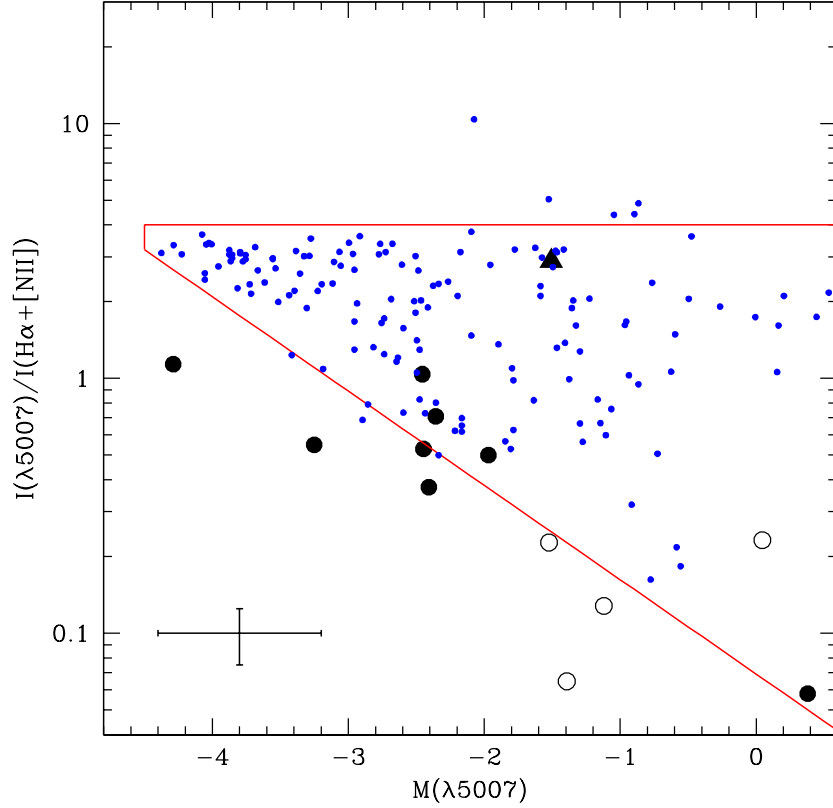


Fig. 2.— The $[O\ III]\ \lambda 5007$ to $H\alpha$ line ratios for the SyN sample used in this paper (large symbols) compared with the $[O\ III]\ \lambda 5007$ to $H\alpha + [N\ II]$ line ratios for PNs in M33 as given by Ciardullo (2004; dots). Different symbols mark IR classification from M97 (filled circles: D-type objects, open circles: S-type, filled triangle: D'-type). The cross in the lower left corner shows typical error bars in the SyN sample. The contour line delineates the PNs populated region, observationally found constant across various galaxies, as defined in Herrmann et al. (2008). Notice that for a clear comparison with PNs the plot is limited to the $M(\lambda 5007)$ -bright region and only the brightest 13 SyNs are visible here; the rest lies to the right of the displayed region.

3. DISCUSSION AND SUMMARY

Even though we use intrinsic properties for the SyNs and measured properties for the extragalactic PNs, the comparison – though crude – is readily justified, as follows. The SyNs lie in the galactic plane and suffer large reddening: the characteristic $E(B-V)$ of SyNs in the sample of M97 is 1–2mag. Not having separate information about interstellar and circumstellar extinction, we use the total reddening values and plot the properties the SyNs would have if completely unobscured. For extragalactic PNs the plots presented in the literature take into account the Milky Way reddening and the estimated reddening within the host galaxy (not always), but not their intrinsic circumstellar extinction, which is usually unknown. However, the typical circumstellar contribution to $E(B-V)$ for PNs is 0.0–0.2mag, and only in rare cases up to ~ 0.5 mag (Ciardullo & Jacoby 1999). The extragalactic PN samples would need relatively little additional de-reddening to be brought to the intrinsic values. Therefore the comparison is more sound than it might seem at a first glance.

Ciardullo (2006b) shows a difference in the diagrams of line ratio vs. [O III] magnitude of PNs in the LMC and in M31 that results from inclusion of the intrinsic reddening. Accounting for the intrinsic obscuration does shift the observed bright tip of the distribution by about 0.8mag, to ~ 0.5 mag above the standard PNLf cutoff value, $M^* \approx -4.5$ mag. However, given our symbiotic sample size, this should not be taken as evidence of a strong difference in the intrinsic $M(\lambda 5007)$ between PNs and SyN, especially since Corradi & Magrini (2006) show that in the Local Group galaxies with PN samples of comparable size the brightest observed PNs can easily fall ~ 1 mag below the cutoff.

Interestingly, Méndez et al. (2008) plot the theoretical evolutionary tracks of PN models from Schönberner et al. (2007) in the [O III]/($H\alpha$ +[N II]) vs. $M(\lambda 5007)$ plane and find that the rising portions of these tracks cluster *below* the observed locus of PNs, exactly in the area which in the present paper is shown to be occupied by SyNs (see Fig.3). Méndez et al. (2008) explain the lack of PNs in this area by the relatively fast evolution of PNs through this region, but it should be stressed that their theoretical tracks display *intrinsic* nebular properties, as no internal reddening was applied to the tracks. Strong intrinsic reddening (as is arguably the case for both SyNs and proto-PNs) removes the objects from this region – they can be compared to the theoretical tracks only when dereddened, as we did here for the SyNs. Notice that in the scenario of Soker (2006) the contamination of the *observed* PNLf by SyNs would most likely occur in the post-symbiotic stage, after the donor has left the AGB, its massive wind ceased, and the intrinsic extinction dropped – but the hot accretor is still the main ionizing source.

The fact that the top of the ISyNLf is dominated by D-type systems is understandable: Mira winds can provide both abundant fuel for nuclear reactions on the accreting white

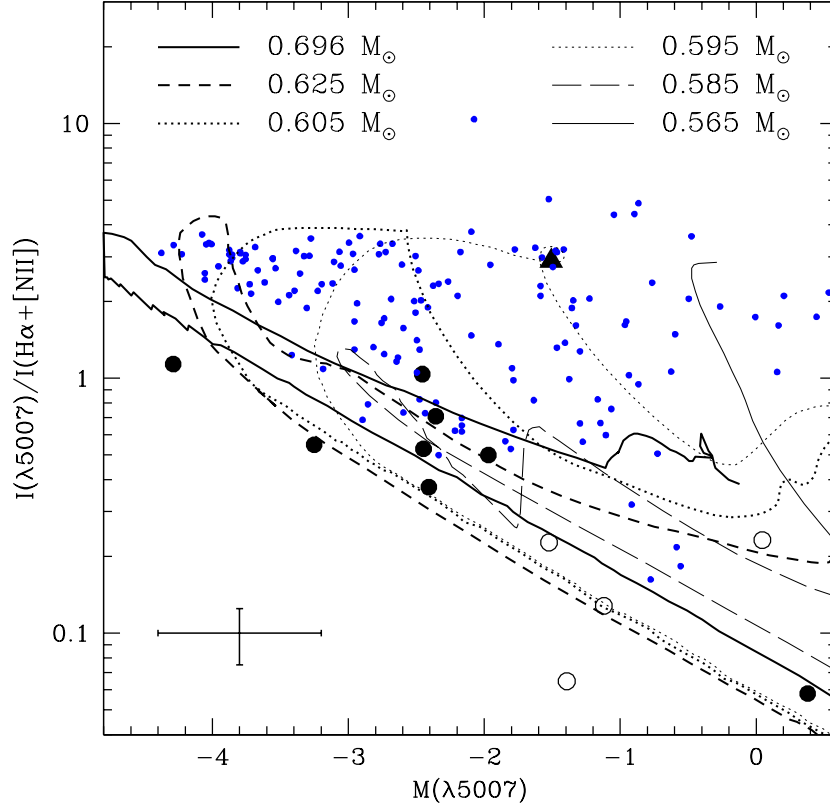


Fig. 3.— Same as Fig. 2 but with PN evolution tracks from Méndez et al. (2008) overplotted. The models show evolution of PNs around post-AGB cores of various masses. Notice how SyNs cover the lower (ascending) portions of the tracks, where PNs are lacking. Notice also the location of the D'-type system HD 330036 among the upper branches of the tracks.

dwarf (WD) and a massive nebula for it to ionize. Although four objects in Figures 2–3 are classified as S-type in M97, every one of them have been considered D-type by some authors (see M97, Belczyński et al. 2000). The undisputed S-type objects are all dimmer than $M(\lambda 5007) = 0.5\text{mag}$. Therefore, the gap in the ISyNLF around $-1-0\text{mag}$ marks the division between the D-type and the S-type systems. Their separation reflects the fact that in SyNs the evolution of the hot component and of the nebula is forced by the mass loss from the giant. It is the D-type objects that are relevant when comparing the upper ISyNLF to the tip of the PNLF. And it is these systems, according to the scenario of Soker (2006), that will consequently contaminate the observed PNLF in their post-symbiotic stage. The only D'-type object in the analyzed sample, HD 330036, falls well into the PN region on the line ratio vs. [O III] magnitude diagram (Fig. 3). This is consistent with the mounting evidence confirming the long-lasting suspicion that the D'-type represents in fact young PNs with a late-type companion (Jorissen et al. 2005).

The similarity between the SyNLF and the PNLF might have different explanations and implications. In this paper we limit ourselves to listing a few of the possibilities: (1) The similarity is a coincidence. (2) The similarity can be explained by the similarity of the ionizing source, a nuclear burning on a compact WD (or a WD in the making), and the similarity of the ionized material, an expanding dense wind of a red giant (RGB or AGB). Binarity of CSPNs plays no role. (3) The similarity results from binarity as well as from the similar ionizing source and a similar origin of nebulae material. In this explanation, the bright PNs owe their brightness, among other things, to a strong binary interaction. We postpone detailed study and discussion of these points to a forthcoming paper.

As a final note, we would like to stress the need for a dedicated search for SyNs in the Magellanic Clouds (MC). Because of their proximity and known distance, MC would be ideal for a study of the PN and SyN population properties in the same environment, while at the same time sidestepping the issue of galactic extinction. Unfortunately, the sample of presently known MC symbiotics is very small (e.g., Belczyński et al. 2000) and, to the best of our knowledge, their line fluxes have not been published. A systematic observational effort is required to enable a direct comparison of the MC PN and SyN luminosity functions.

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Table 1: Parameters of the SyNs with $M(\lambda 5007) < -2\text{mag}$, i.e., up to 2.5mag from the standard PNLf cutoff, $M^* \approx -4.5\text{mag}$ (contained in the three top bins of the ISyNLF in Fig 1). Observed fluxes are in units of $10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$.

Name	$F(\text{H}\alpha)^a$	$F(\lambda 5007)^a$	$E(B-V)^a$	d^a [kpc]	$M(\lambda 5007)$ mag	$\frac{I(\lambda 5007)}{I(\text{H}\alpha)}$
V835 Cen	411.40	66.30	2.0	1.9	-4.29	1.14
H2-38	179.70	33.70	1.1	7.2	-3.25	0.55
He2-171	47.60	12.60	1.4	5.0	-2.46	1.04
V704 Cen	7.20	0.88	1.5	16.0	-2.45	0.53
He2-38	518.80	44.90	1.5	2.2	-2.41	0.37
V852 Cen ^b	215.43	57.57	1.0	4.3	-2.36	0.71

^a From Mikolajewska et al. (1997)

^b Fluxes shown for this object are averages from 3 measurements